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In a discussion of human institutions and modes of conduct, a basic analytical shift from absolutism to relativism is noted. From this frame of reference the conceptual changes in mathematics, the sciences, and esthetics are reviewed. The paper also discusses the implications of this change for the psychology of human thinking and for children's thinking in particular. Two processes are postulated: "the expression of possibilities" and "the analysis of implications." Each process, moreover, involves very different attitudes toward error. Children who are skilled in the analysis of implications but poor in expressing conceptual possibilities have an overly severe attitude toward their own errors and, therefore, may avoid risk-taking, potentially innovative, activities. The "hardware revolution" in education--instruction by teaching machines and computers--not only stultifies the process of expressing possibilities but will inevitably lead to increased stress on a curriculum that can be taught by machines. This may in fact lead education back to an overly rationalistic view of thinking processes. (NH)

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Creativity and the Expression of Possibilities[1]

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In the growing amount of lip-service that is paid in our culture to "creativity" there is divulged, I think, an awareness that something about human endeavor and human nature that was heretofore a background phenomenon now has emerged for explicit consideration. Only because modern man has become, if you will, sufficiently self-conscious about how he functions psychologically and socially--as reflected in the growth of the social sciences over the last few generations--has this awareness of which I speak become increasingly prominent. Such emphasis upon the social sciences seems to betoken a basic shift from absolutism to relativism in the definition of human institutions and modes of conduct--a realization that, no matter what range of characteristics may constitute invariants of human nature, man nevertheless is considerably more plastic or fluid, more open to possibilities in how he thinks and how he behaves, than could ever have been believed even as recently as fifty years ago.

UD 004 553

The shift that I have just mentioned seems to be related to a quite general rethinking that has taken place in recent decades concerning the nature of mathematics, science, and the arts--in other words, much of man's distinctively human endeavors. I should like to describe, first of all, my view of this conceptual change concerning mathematical, scientific,

and aesthetic affairs. Then I want to suggest what this change seems to imply concerning the psychology of human thinking, and to review some relevant evidence on children's thinking in particular. After considering certain major characteristics of how thinking proceeds, finally, I want to turn to a very practical social issue on which I feel the earlier discussion has a direct bearing: namely, the advent of instruction by teaching machines and computerized devices.

Mathematical, Scientific, and Aesthetic Activity

It was not until the last few generations that clear status became awarded to a fundamentally arbitrary, conjectural, or constructivist element in the range of human activities comprised by mathematics, science, and aesthetics. Let us look first at an example in a branch of mathematics--geometry. Out of a concern for trying to understand the nature of physical space, Euclid set forth a number of concepts relating to space--such as "straight line" and "point"--and a number of propositions that specified particular relationships among these concepts. The propositions were called postulates, and from these postulates other information--described as theorems that followed from the postulates--could be deduced.

What did Euclid think he was doing when he devised his geometry? He believed that he was setting forth postulates that were obviously--that is, intuitively--true as descriptions of the nature of physical space, and then obtaining new information about space by determining what those postulates implied by way of theorems. The theorems were considered to convey new

information because they could generate surprise in the person making the deductions--even though, in principle, the theorems were contained by the postulates in the sense of following by logical deduction from the postulates alone. Deduction of the theorems thus was appropriately construed as an advancement of knowledge, since only an omniscient genius would be blessed with the power to see at a glance all the theorems that the postulates implied. What Euclid--and many geometers after him--seemed to confuse, however, was that the canon of correctness determining whether a theorem had been appropriately inferred from given postulates had nothing to do with whether the theorem or the postulates were true as statements about the nature of physical space. There were, in other words, two kinds of truth and falsity involved here, not just one. There was the question of whether the logical operations for deriving theorems from postulates had been correctly performed--whether translation rules had been correctly applied; and there was the question of whether the postulates and theorems provided correct descriptions of what space was like.

For a long time nobody was particularly concerned with the second kind of truth and falsity when considering geometry. Euclid and other geometers simply believed that learning about space only involved making sure that the path from postulates to theorems had been correctly traversed. Who could question whether the postulates were correct? They were presumed to follow intuitively from the nature of space. Concealed from view, therefore, was a crucially important psychological process which Euclid

had performed. The invention of the postulate system itself had involved the construction of a set of possibilities: in other words, it was in fact an invention and not just a discovery of how the world was constituted. There was an element of arbitrariness involved--a choice of some postulates rather than others.

In order to reveal the setting up of postulates in geometry as in some degree an act of conjecture, a proposal, the history of geometry had to wait for the invention of other self-consistent sets of postulates that could be entertained as alternative possibilities to the set devised by Euclid. The mathematician as a generator or producer of possible sets of assumptions then came to be recognized as a new role to be placed alongside that of the mathematician as a translator who traces the steps of a logical derivation. In regard to their nature as geometries, or kinds of mathematical systems, there is, of course, nothing to choose between Euclid's geometry or one or another system of non-Euclidean geometry. Thus, for example, one mathematician, Riemann, developed a system of geometry involving the postulate that straight lines always meet somewhere. Contrast this with Euclid's assumption that for any given straight line there can be drawn through any point not on that first straight line a second line that is parallel to the first. Riemann would assume, rather, that no parallel can ever be drawn to a straight line through a point not on that straight line. As long as Riemann's set of postulates is consistent within itself, then it is as valid a geometry as that offered by Euclid. The two geometers have invented or created equally self-consistent postulate sets. Theorems inferred from one set will

be no better or worse than--only different from--theorems inferred from the other set.[2]

Mathematics is a game, therefore, involving the generation of conceptual possibilities--one or another postulate system--and the tracing out of their logical implications. What about science? Here the other kind of truth and falsity mentioned previously comes into consideration. When a scientist forms a theory, he sets up definitions of concepts and states propositions stipulating how these concepts are related--thus far, his behavior resembles that of the mathematician. However, the theorems that the scientist infers from these propositions or assumptions constitute predictions--hypotheses--about observable characteristics of the environment. Not only, then, is the scientist interested in being correct regarding how he goes about inferring predictions from his initial postulates, but he also would like these predictions to be ratified by experience. To the extent that they are confirmed in this way, he can feel more confident about the assumptions--the theory--from which he started.

The matter may be illustrated by returning now to the Euclidean and Riemannian forms of geometry and considering what is necessary in order to transmute them from systems of mathematics into scientific theories. The postulates must be given physical interpretations--that is, the concepts and the rules for relating them must be coordinated to operations that can be performed on the environment. By proceeding in this manner, Euclidean and Riemannian geometry can become alternative possible scientific theories

about what space is like. If, for example, one proceeds to give the concept of "straight line" the physical interpretation of "light ray," experiments involving astronomical distances can be performed which demonstrate that Riemann's postulates actually offer a better description of the nature of extensive ranges of space than do those of Euclid. Since light rays follow a curved path in the sun's gravitational field, Euclid's postulate that a parallel can be drawn to a straight line through any point not on that straight line does not provide as good a fit to reality as Riemann's postulate that the lines in question must meet somewhere.[3]

The proposed concepts and the proposed relationships interconnecting them that constitute a scientific theory thus are subject in principle to criteria of evaluation that are lacking in the case of a system of mathematics. As in the case of the mathematician, however, two rather different forms of psychological activity can be found in the scientist's mode of conduct: he must invent or generate his theory, and he must trace his way along the deductive path that will lead him from the starting points provided by his postulates to the proving ground provided by his experimental predictions. It was a relatively recent realization on the part of philosophers of science (e.g., Hempel) that there remains a goodly degree of arbitrariness in the scientist's choice of postulates, in that the only major constraint operating upon him consists of whether the predictions he can deduce for test receive confirmation.[4] To be sure, there are questions of consistency among the postulates chosen and questions of parsimony, but these apply to the

mathematician as well. Since the proof of the pudding only is in the eating, the scientist is free to seek his theoretical postulates wherever his fancy may lead him. He may, as a physicist, for example, seek to comprehend--i.e., make confirmable predictions about--electrical phenomena by drawing his postulates from the ways in which water behaves in pipes. He can juxtapose elements of his experience, make use of analogical and metaphorical thinking, in as free-wheeling a manner as he wishes.

Often, in fact, important advances in the ability of a branch of science to predict phenomena of interest to it have been found to depend upon the generating of new postulate systems through such processes as what one scientist--Einstein--has referred to as "associative play" and "combinatory play."[5] In this respect, science as well as mathematics would seem to have its game-like properties. An attitude that betokens the playful entertaining of possibilities--the setting of a wide latitude of acceptance limits regarding how the individual will permit himself to think about a subject--may be present in practitioners who are at the cutting edge of each of these domains of knowledge.

We have drawn, then, a distinction between two psychological phases in the work of either a mathematician or a scientist--the generation of conceptual possibilities and the rational deduction of what these possibilities imply within some logical structure. In making this distinction we have emphasized the growing realization that has occurred in recent examinations of the nature of mathematics and science to the effect that the first of these

phases--generation or invention of possibilities--involves the constructing of combinations and juxtapositions of concepts in ways that smack of the arbitrary and that suggest a considerable emphasis upon tolerance for conjecture--conjecture as to what may be aesthetically pleasing in mathematics, conjecture as to what may be predictively useful in science. Postulates, then, whether mathematical or scientific, are not given in nature--not discovered--but rather are built by recourse to the exploration of combinatorial or associational possibilities. Since it is human beings who devise the postulates, the latter will, of course, relate to what people have experienced of nature, but in no way that automatically or intuitively confers truth status upon the postulates. Rather, in mathematics, criteria of truth and falsity do not apply to postulates at all, while in science, criteria of truth and falsity apply to the hypotheses derived from the postulates--and as we saw in the case of Riemann, predictions that turn out to be confirmed by experience can often be found to derive from postulates which, if anything, would be declared false on intuitive grounds. Strange, counter-intuitive scientific theories can lead to confirmable predictions.

Let us turn now to man's aesthetic activities. The human being as an artist or composer or writer seems to function very much as the human being does who devises systems of mathematics. Just as the invention of alternative systems of mathematics in recent years--non-Euclidean geometries, non-Aristotelean logics--has pointed to an arbitrary, constructivist element in the establishing of postulate sets, so also the

growing awareness in recent years of the multiplicity of human cultures and the increasingly rapid dissemination of new art forms has led to the realization that a comparable element of the arbitrary and the conjectural underlies aesthetics. For such a realization to come about, it probably was necessary that Western European man be dethroned from the position of assumed eminence over the rest of the world's cultures and over earlier civilizations that, until recently, was awarded him by those who provided his philosophy and his chronicles of history and society. It is this dethroning, in fact, that may have contributed heavily to the sudden spurt we have witnessed in the timetable by which aesthetic forms succeed one another.

Until about the last hundred years or so, it was relatively easy for a person who was reared in the Western European cultural tradition to assume that there were some clear paths of progress for the evolution of artistic forms. True, there had been setbacks in the pursuit of these lines of development, as when the classical world was destroyed by hordes of barbarian invaders, but the paths themselves nevertheless remained evident. Just as Euclid could believe his postulates to be intuitively true, so the assumptions underlying musical composition or painting, for example, could be thought of as basically correct in the sense of being attuned to the universal conditions that would maximize aesthetic pleasure. Change there was, to be sure, but only of limited kinds: assumptions were clarified and polished as time went on, and those who worked in the arts became more expert at deriving consequences from these assumptions--carrying out

aesthetic projects that were stylistically consistent with what the assumptions called for, i.e., were "good exemplars" of the given aesthetic style. But the basic assumptions themselves were not questioned.

Consider an example first with regard to painting, and then we shall turn to one regarding music. Assuming that painting should be representational--i.e., that art should be, as he put it, "...the sole imitator of all visible works of nature"--da Vinci[6] tried to clarify and make explicit the postulates required for achieving maximum veridicality in one's painting. In his detailed writings about, for instance, perspective and light, he tried to set down propositions which, if followed, would yield paintings that looked as real as possible. A particular painting, then, was a derivation from these postulates, and can be judged for the degree of its consistency with the rules that da Vinci claimed to be following. Few artists, of course, wrote down what they viewed as their aesthetic postulates in the manner that da Vinci did, and so for most artists it is more difficult to determine how consistent a given art product is with the canons that provide the artist with his starting point. In principle, however, this exercise can be carried out in most cases, since one can--often with considerable accuracy--infer the postulates that guided the work of a given artist from a knowledge of when and where he lived, with whom he studied, and what art he admired. Although the criteria for judging consistency and inconsistency of a painting with the artist's postulates are necessarily going to be ambiguous in some degree, the situation otherwise is not unlike that of determining whether a

given mathematical theorem is consistent with--and hence derived correctly from--a given set of mathematical postulates. And, of course, da Vinci made the same mistake that we ascribed to Euclid: namely, believing that the postulates were intuitively valid--or at most, in need of minor modifications that would bring them into line with what would make for maximum veridicality in one's paintings. Da Vinci once again, then, believed himself to be discovering rather than inventing and constructing.

It is evident at this point in time, however, that the postulates used by da Vinci and by others painting in similar ways can be questioned as such. Representational veridicality need not be a goal of painting. Other sets of postulates that have nothing to do with that goal, but rather with--for example--what are viewed as aesthetically permissible combinations of abstract line forms, may be erected in place of da Vinci's postulates. As there are non-Aristotelean systems of logic and non-Euclidean geometries, so also there are traditions of visual art that take their departures from a variety of stylistic starting-points.

The same conclusion is evident when we consider the composition of music. For a long time it was believed in the Western world that certain principles concerning admissible harmonic combinations and certain rules of counterpoint provided an intuitively appropriate aesthetic basis for writing music. A fundamental set of postulates emerged, in other words, that was presumed to provide the starting point from which all musical composition should set forth. With respect to harmonic postulates, for

example, it was assumed that the musical interval of the third constituted the basic building block in terms of which chords should be constructed--that chords built in terms of thirds generated maximum aesthetic pleasure. To be avoided, or at best to be introduced by surrounding it with various kinds of harmonic apologies, was the interval of the fourth, which was considered--again presumably on intuitive grounds--to be displeasing to the ear.[7]

The intuitive basis of such a decision is hard to accept, however, when one considers that the reverse set of harmonic assumptions regarding the use of thirds and fourths can be found exemplified in the music of India, where the fourth is considered a pleasing musical interval while the third is not.[8] So also, recent developments in Western music have included the emergence of new styles that involve different postulates of composition than those embodied in the traditional music of the West. For instance, as in the case of Indian music, the work of Schoenberg--a Western composer--also emphasizes fourths rather than thirds as a basic interval. Schoenberg reached his decision to emphasize fourths by wishing to give equal status to all twelve of the tones that lie within an octave, in contrast to the convention in classical Western music of emphasizing three tones, each of which is separated from the next by an interval of a third. He found that if one traversed the keyboard in fourths one would touch the twelve different tones contained by an octave and then return to the point of origin, without having touched any tone more than once. Such an outcome led

Schoenberg to conclude that the fourth hence would be the proper interval on which he should center his attention.[9]

The typical citizen of India with musical experience will, of course, find the music of his country more pleasing than music in the classical tradition of Western Europe. So too, Europeans who listen to enough of the music of Schoenberg and other twelve-tone composers will often come to find music of that kind pleasing--once they have, by exposure to it, become sufficiently familiar with the particular premises of its composition. Alternative sets of harmonic and melodic postulates can be fashioned, then, and music written which is stylistically consistent with one or another set. As in the case of visual art, one can in principle expect to be able to discriminate better from less good embodiments of a particular compositional style, once one can define with sufficient clarity the stylistic postulates that a given composer believes himself to be following. Particular compositions are, in this sense, "theorems" that derive from a set of postulates as to how music should be written, and one can determine how consistent a given composition is with the rules by which its composer wishes to work. But just as there is nothing to choose between alternative geometries as systems, so also one cannot adjudicate between classical harmony and the harmonic rules used in, say, twelve-tone music. There is no "rational" or intuitively self-evident ground for claiming that one or the other system of musical assumptions is aesthetically superior. Rather, they are different, and each can form the basis for a composer's work.

As was shown to be the case for mathematics and for science, then, so also when it comes to man's aesthetic activities there seem to be two distinguishable kinds of psychological processes that take place: the construction of a set of premises--on at least partly arbitrary grounds--as to what are to be the ground rules; and then the exploration of the consequences implied by these rules. Just as recent thinking in mathematics and science has come to call attention to the multitudinous bases upon which postulate sets or theories can be erected, so also recent aesthetic criticism has come to emphasize the importance of the artist as empowered not only to trace through the implications of a given set of aesthetic assumptions--to work within a given style--but also to invent and try out different sets of possible assumptions.

Thus, for instance, we find the critic Susan Sontag advising much the same kind of thing in art to which Einstein called attention in physics--the need for engaging in associative play and combinatory play regarding the putting together of conceptual elements in order to generate new possible starting points.[10] By juxtaposing, by putting into association, elements that have not previously been viewed as related, new possibilities emerge on which aesthetic, mathematical, or scientific traditions can be founded. Sontag is particularly interested in forms of art which emphasize the artist's role as a provider of new possibilities, new juxtapositions of elements from experience. In cubism, for example, parts of familiar objects are placed in new associations and connections with one another. In surrealism, a

familiar object will be placed in a context with which it was not heretofore joined. As a result the object is rendered strange, as it were, and filled with new evocative power. In "pop" art, a similar evocation of the strange by the familiar is achieved by juxtaposing an everyday object such as a can of soup with an environment--the museum--that carries connotations from an entirely different domain of experience. So, too, the music of a composer such as John Cage will involve the use of a piano that has been systematically rebuilt so as to provide a different repertoire of available tonal qualities. And a play by Jean Genet will involve an experiment with the unfamiliar juxtaposition of having black people impersonate white people.

No doubt Sontag may fall prone to an excessive celebration of the unique for its own sake, but the fact remains that she is representative of a new wave of awareness in the arts that aesthetic assumptions are in large measure constructed by man rather than given in nature, and hence are fair game for experimentation. The discipline of working systematically within a particular set of assumptions in order to explore their implications is, of course, important as well. But some excess in Sontag's direction seems quite excusable at this point since one is describing a realization that has come about only over the last few generations of man's long aesthetic history. It has become evident, then, that the artist can appropriately devote effort to the building of new ways of combining and relating aesthetic materials; he need not only restrict himself to working with

systems that already exist.

On the Psychology of Human Thinking

In mathematics, in science, and in art, we have found evidence for two phases of human endeavor--the setting up of conceptual possibilities and the analysis of what these possibilities imply. We have noted that the first phase, that of constructing assumptions, has been masked from view until relatively recently in human history by the belief that the process at issue was not in fact one of invention or conjecture but rather one of intuitive apprehension or analysis concerning how nature is ordered. Man's thinking in all of the areas that we have described hence seems to be characterized, on the one hand, by the generation or production of ideational possibilities, and, on the other, by taking a particular set of such possibilities--with its system of logic as to what else the set implies--and examining deductively the set's implications. We may call the first of these processes the expression of possibilities; the second, the analysis of implications. I would like to suggest that the two processes involve very different attitudes toward error.

The analysis of implications refers to the kind of activity that is traditionally associated with tests of intellective ability and of academic achievement in our society. Called for on such tests is the close separation of what is "right" from what is "wrong" in terms of some given set of premises which the respondent must have within his grasp in order to proceed effectively. In the case of ability tests, the premises or postulates

are sufficiently general that they are presumed to be familiar to everybody--as when the respondent's degree of clarity of understanding of the words in his language is tested; or the premises are supplied with the test--as when the conditions of some problem are set forth and the respondent is asked to solve it. In each of these situations, the psychological issue is presumed to consist in how well the child can manipulate some givens--how precisely his verbal behavior will reflect, for example, the rules for word usage in his culture, or how incisively he can reason about what the solution to a problem must be in light of the data that have been presented. Tests of academic achievement, on the other hand, presumably require the child not only to demonstrate the ability to make correct inferences, but also to show that he has mastered the premises in one or another area of knowledge--such as the particular vocabulary needed for describing the history of America in the eighteenth century or the particular symbols used for presenting numerical problems in algebraic form.

In point of fact, however, the distinction between ability and achievement, or between intelligence tests and tests of academic accomplishment, is difficult to maintain in practice. Those children who score high on ability indicators also tend to score high on academic achievement indicators as well. Furthermore, children scoring high regarding measures of verbal ability also tend to score high on measures of quantitative ability, and children who score high regarding one area of potential academic accomplishment represented in their school curriculum also tend to score high when it

comes to other academic achievement areas that form part of their curriculum.[11] There is, then, some single dimension of relative proficiency in terms of which children are ordered by all of these instruments, whether the tests are described as measures of one or another kind of intelligence or as indices of one or another type of school achievement.

Since the degree of specificity of the experience needed for dealing successfully with the test materials varies over a considerable range and yet children tend to exhibit a consistent level of proficiency on all of these types of tests, the intensity of a child's relative exposure to the sorts of materials that form the concern of these tests doesn't seem to constitute the determining factor in his performance. Rather, what seems to be at issue is the child's skill in using analytic systems correctly--in carrying out translations and transformations of information in ways that conform to the logical requirements that are prescribed in his culture and that are assumed or stipulated on the tests. In order to know how to transform and how to translate, one must be able to retain the rules of the system and have a sharp sense of discrimination for what is and what isn't permissible in the light of those rules. It is apparently the case--on the basis of the evidence--that the capacity to analyze implications correctly represents a very generic type of thinking skill that transfers with alacrity from one substantive domain to another. This is the kind of ability to which the notion of "general intelligence" seems to refer, and it is what we have found to be at issue in the work of a mathematician, a scientist, or an artist as he

seeks to move toward some product or goal that is consistent with a set of starting assumptions--whether these assumptions be mathematical postulates, a scientific theory, or rules of harmony.

In the exercise of intelligence, the individual as he works in any area of content must be highly sensitive to error. Analysis of implications requires that a true course be maintained with respect to one's premises, however vague and unverbalized these may be. For a mathematician or scientist, the postulates from which one works will be quite explicit indeed: they can be written down in a list. But for a cubist painter, or for a child or adult demonstrating his knowledge of the principles of grammar by distinguishing correct from incorrect examples of speech, the assumptions may be difficult to render explicit and yet the person will be described by knowledgeable others as using the assumptions correctly. What of the kind of thinking, on the other hand, that is involved in the expression or generating of possibilities? When a person constructs a set of assumptions, when he entertains a conjecture as to particular concepts that may go together, when he juxtaposes elements of his experience that neither he nor anyone else had previously placed in association, what can we expect to be the attitude that the person maintains toward error? In this latter case, it seems to me, a very different attitude toward error can be expected: tolerance instead of severity.

An attitude of relaxed contemplation of possibilities can be found in many introspective accounts concerning moments of personal creativity or

inventiveness, as these accounts have been culled from interview and diary material provided by artists, mathematicians, and scientists.[12] One can point to a sense of playful experimentation in which the danger of error has relatively little significance. Recall Einstein's references to "associative play" and "combinatory play." It is as if judgment becomes suspended in some degree, and leeway is provided for the entertaining of unusual concatenations of ideas and images. To suggest that there is relatively little attention paid to the possibility of error in this kind of thinking is to say that the person doing the thinking does not view error as a source of disgrace, as a way to lose face. A permissiveness with respect to error that can never be tolerated when one is engaged in the analysis of implications, therefore, may well take on importance if one is seeking to express or generate possibilities.

While our society has paid considerable attention to evaluating how proficient a person is at analyzing implications, much less concern was paid until very recently to the question of a person's capacity for generating unusual ideas and regrouping elements of experience in fresh ways. I would speculate that the reason for this neglect stems from the historical situation described earlier with respect to mathematics, science, and the arts, where the prevailing assumption was for a very long time that analysis of "what is there"--intuitive apprehension of some order of givens--provides the appropriate starting points for work in each of these domains. If that were the case, then something on the order of general intelligence

would be the only kind of attribute that would require measurement. Our reading of the recent history of these human activities, on the other hand, has suggested a different perspective.

A question that immediately arises, however, is whether this different perspective is operationally distinguishable from the one that formerly prevailed. If not, then the psychological utility of distinguishing between analysis of implications and expression of possibilities in man's thinking would be doubtful, even though the distinction could be defended on epistemological grounds. To put the operational issue directly, we need to inquire whether the individuals who possess greater intelligence--i.e., the persons who are better able to analyze implications--are the same as the individuals who possess greater ability to conjure up conceptual possibilities. At first blush it looks as if these persons should indeed be one and the same. After all, isn't an inventive or creative scientist going to be more intelligent than one who is less inventive or less creative? On the other hand, if different attitudes toward error are involved in analyzing implications and in expressing possibilities, then the psychological picture might be more complex.

The answer seems to be that if you test for the ability to express conceptual possibilities under conditions that threaten the individual with penalties for error, proficiency at constructing possibilities will tend to be found only in the case of the persons who also are skilled at analyzing implications. However, if you test for the ability to express conceptual

possibilities under conditions that maximize freedom and permissiveness with respect to error--so that the chance of making a mistake does not constitute a threat--then proficiency at constructing possibilities turns out to be quite independent of the ability to analyze implications.[13] Under these latter conditions, some persons who are skilled at analyzing implications turn out to be skilled at expressing conceptual possibilities as well, but others who are skilled at analyzing implications are found to be poor at generating conceptual possibilities. So too, while some persons who are poor at analyzing implications also are poor at expressing conceptual possibilities, others who are poor at analyzing implications turn out to be highly skilled at producing conceptual possibilities. There is, in short, no relationship between the two kinds of thinking skills, when the ability to generate conceptual possibilities is assessed in a way that frees the person from the fear of making mistakes.

We have proposed, in turn, that a permissive attitude toward error is more conducive to the type of thinking that is concerned with generating possibilities than is a severe or punitive attitude toward error. The ability to construct possibilities thus is found to be independent of the ability to analyze implications precisely under those circumstances that should be propitious to the former's display.

The type of evidence on which the preceding statements rest includes the following. In some of our recent research, the generating of conceptual possibilities was assessed in fifth-grade children with various kinds of

materials. For example, an object would be named, such as a shoe or a newspaper, and the child would be asked to mention as many uses as possible that he could think of for the object. These requests took place in a play context, with the child encouraged to take as much time in responding as he wished. Fear of error thus was minimized. Under such circumstances, the number of conceptual possibilities that the child generates, and the number that he presents which are unusual in the sense of being his personal possession rather than being ones which other children think of as well, are found to be quite independent of how "bright" or "dull" the child is in terms of general intelligence indicators.[14] On the other hand, comparable work by other investigators has involved the use of similar procedures which were administered, however, under circumstances that emphasized a test-like context and hence implied that error was to be penalized. The generating of conceptual possibilities in the latter type of setting, where there is no permissive attitude toward error, tends to co-vary with level of general intelligence.[15]

In sum, then, we find that the ability to analyze implications, with its requirement of alertness and sensitivity to the possibility of error, tells us nothing about a child's ability to suggest unusual and plentiful conceptual possibilities in situations where no penalty for error is present. A child is just as likely to be skilled at one of these types of thinking and poor at the other as he is to be skilled at both or poor at both. If analysis of implications requires sensitivity regarding possible errors while the

expression of conceptual possibilities requires permissiveness regarding possible errors, what can we say by way of characterizing the individuals who are proficient with respect to both abilities, proficient at one but not the other, and proficient at neither?

Something like the following characterizations would seem to apply. The child who displays high levels of both abilities must be capable of shifting with flexibility from an attitude of error tolerance to an attitude of error rejection, as a function of what he is working on. By contrast, a child with strong ability to analyze implications and low ability to entertain conceptual possibilities must be rigidly locked in an attitude of error rejection--the chance of error is not to be tolerated. For the child who is unable to analyze implications skillfully but nevertheless shows a high ability to generate conceptual possibilities, on the other hand, the opposite kind of inflexibility appears to prevail--namely, a pervasive attitude of error tolerance which the child is unable or unwilling to modulate. The child who is low in regard to both abilities, finally, gives no evidence of possessing specific attitudes of error tolerance or of error rejection; there is relatively little behavior to suggest selective permissiveness or selective minimization of the possibility of error.

In terms of pedagogy, I feel that the clearest educational challenge exists in the case of the children who are relatively able to analyze implications but relatively unable to generate conceptual possibilities. There is little doubt that, as educational environments become richer and teachers

become equipped with a wider variety of technical aids, general improvements can take place in the level of analytic skills possessed by children who are initially poor at analysis of implications. The gradual rise in scores on intellective-ability tests that we have witnessed over recent years testifies to this kind of pedagogical effect. It is an effect, however, that amounts to cultivating "more of the same," since we have found that sensitivity to what is correct and incorrect in terms of given rule systems already constitutes the very core of what qualifies in our society as educability and as educational achievement. The educational message that gets communicated to those children who are capable of analyzing implications but poor at producing conceptual possibilities, on the other hand, represents in my estimation a serious deception. These children are informed that as far as the society is concerned, they are doing fine educationally. Yet, they cannot adopt the kind of tolerance toward error that may lie at the root of much significant innovation in mathematics, science, and the arts. The challenge for education, then,is to do something different for these children--something that may have the effect of freeing them from an inflexibly maintained attitude of avoidance toward error. It would seem that they need to learn that circumstances exist under which it is an acceptable practice to withhold one's judgment about correctness or incorrectness--to live with the chance of making a mistake.

Before considering the educational situation further, however, we should ask whether there is any independent evidence to suggest that the kind of

children whom we have described as pervasively oriented toward error rejection do in fact behave that way. Thus far, we have inferred this orientation from the conjunction in their case of high analytic skills coupled with low ability to suggest conceptual possibilities. Is there direct evidence to support this interpretation? Several studies in our recent research do, in fact, provide such support.[16] For example, the children in question are found to be particularly unlikely to entertain the possibility of describing schematic drawings of people in affective terms that could be considered bizarre--but nevertheless might possess some validity. So also, these children turn out to be particularly unlikely to engage in kinds of classroom behaviors that appear disruptive to an independent observer, and they are relatively hesitant about speaking out in the course of classroom discussions. While others seek out these children as friends, furthermore, the children in question are themselves relatively reticent to express friendship strivings toward others. At least one characteristic of the children under consideration which these strands of evidence seem to have in common is an attitude of avoiding activities that may incur error--that may turn out to have been a mistake. It is as if the risk of making mistakes in one's judgment--in social matters as well as in cognitive matters--is not to be chanced.

In the case of children who are skilled at the analysis of implications but poor at the expressing of conceptual possibilities, then, we have persons who may be barred from performing innovative roles in the society by virtue

of their overly severe attitude toward error, but yet who are told by the educational system that nothing is lacking in their performance. As far as the schools are concerned, these children are very intelligent and show high scholastic achievement: their performances on tests of intellective ability and on tests of academic accomplishment are unimpeachable. The educational arrangements that presently exist, therefore, are letting these children down. Does it appear that any help for them will be forthcoming in the educational system of the future?

The Hardware Revolution in American Education

The future looks very bleak to me for these children. The new wave in American education at the elementary and high school levels will from all indications consist of an emphasis upon instruction by teaching machines and by computers. What is such instruction like and what kind of thinking does it aid?

By and large, the major characteristic that distinguishes automated forms of instruction from ordinary books is the immediacy and specificity of feedback that can be provided to the child concerning the correctness or incorrectness of answers that he offers. The hallmark of the technique is the provision to the child of a "responsive environment," to take a term that derives from the name of a company that manufactures one of the new kinds of computerized teaching machines: that is, an environment that offers immediate evaluative criteria to the child for judging the answers that he provides to questions, and that by its evaluation guides

the child's behavior toward the making of more and more correct responses and fewer and fewer incorrect ones.

Consider how this principle of immediate and specific feedback works at each of two levels of hardware complexity. In some of the simpler teaching machine devices of the kind originated by B. F. Skinner, a question appears in the machine's window when the student turns a knob. The student writes his answer to the question and then turns the knob again so that his written answer slides up under a transparent cover and thus cannot be altered. The correct answer then immediately moves into the student's view, letting him know thereby whether his own answer was right or wrong. In some of the more complex devices, such as those developed by O. K. Moore, Richard Kobler, and others, the child may sit at a typewriter keyboard and hear a request over a loudspeaker from a tape recording that asks him to spell a particular word. If the student types a correct letter, the letter appears on a screen in front of him; if he types an erroneous letter, on the other hand, it does not appear on the screen and the recorded voice informs him that the letter is wrong and he should try again. Persistent error at a letter may finally lead to the machine's presenting the word spelled correctly on the screen, followed by a request from the loudspeaker that the child now try again. In another device, the child sees a question on a television screen and chooses what he believes to be the correct answer by pointing a flashlight at one of the multiple-choice alternatives that appear on the screen. A voice then informs

the child whether the answer he selected was right or wrong.[17]

There is little doubt that automated instructional devices will gain increasing influence as a means of pedagogy, and this for two reasons. First, the use of instrumentation is highly consonant with the dominant American value pattern, deriving as this pattern does from the extensive homage paid by our society to physics and engineering. Hardware--electronic if possible, mechanical if not--tends per se to be taken as a sign of progress. Second, various industries in this country are developing a sizeable financial stake in the propagation of automated instruction, and are not likely to treat these investments lightly. Thus, a number of electronics and computer firms have obtained connections with firms concerned with the preparation of educational materials.

It seems to me that the impact of automated instruction will be to provide an all the greater emphasis upon the kind of thinking defined by what we have called the ability to analyze implications. As we have seen, the cardinal virtue possessed by automated instruction over ordinary reading matter is the provision of immediate and specific evaluative feedback to the child. Automated devices thus can be expected to be particularly suited to the teaching of rule systems--systems for translating or transforming cognitive elements--and indeed it is in this kind of area that their major successes have been achieved.[18] A teaching machine offers an efficient means of instructing a child in how to spell, or in how to read, or in how to work arithmetic problems, or in how to learn vocabulary. These

are kinds of tasks that involve orienting the child as to what constitute correct and incorrect inferences within a prescribed set of givens, such as number rules, spelling rules, or grammar rules. At least one source of the considerable power possessed by automated instruction for the kinds of tasks in question is that the child can be encouraged to apply the rules correctly without having to go through attempts to teach him explicit verbal forms of these rules. It is the case, after all, that knowing explicit overt statements of rules can often be a very different matter from knowing how to work correctly with rules, and much of education has concentrated upon the former while taking its goal as the latter.

What worries me, however, is that the socio-cultural support behind automated instructional devices will inevitably lead to increased emphasis in the schools on whatever it is that can best be taught through the use of these devices. And this means, of course, a further emphasis upon that which already is central: the kinds of skills represented by intellective-ability tests and by indicators of how well the child has mastered academic content domains. Automated instructional devices, even more than intelligence tests themselves, will convey to the child the message that the world is made up of analytic systems and that the child's task is to master these systems. Immediate and focused feedback as to correctness and error signifies all the more dramatically to the child that right answers are the primary virtue in school: that one should conduct oneself so as to achieve correct answers as quickly and consistently as possible.

Clearly, this is not the kind of pedagogical orientation that will stimulate an entertaining of conceptual possibilities that are deviant and far-fetched and hence well may be wrong. A tolerant attitude toward the possibility of error--a withholding of evaluative judgment in order to generate novel analogical or metaphorical connections between ideas that have not previously been juxtaposed--this is not the kind of thinking to which automated instructional devices lend themselves. Children who are skilled at analysis of implications but poor at generating conceptual possibilities, therefore, are likely to become, if anything, all the more set in their overly severe attitude toward error with the advent of automated instruction. And, if anything, the awarding of increa sing ideological prominence in educational circles to automated instructional devices suggests that it will become increasingly difficult in general to win educational recognition for the importance of developing times and places wherein evaluation is withheld and the trying out of possibilities encouraged.

While some proponents of automated instruction try to argue otherwise--that the use of such devices will free the teacher for pursuit of other educational goals[19]--I strongly doubt that such will be the outcome. Given the overwhelming commitment of our society to science and technology as a prime value, and given a growing industrial commitment to the propagation of automated instruction as the way in which education should be carried out, I find it hard to conceive of non-automated instruction in any role other than that of second-class citizen. The teachers will not be on the top of the

pyramid, freed from disagreeable chores by labor-saving machines. Rather, on the top of the pyramid will be the educational engineers who fashion devices and programs for automated instruction, and the educational administrators who route the students through these devices and programs.

Viewed in this perspective, it turns out, ironically enough, that automated instructional devices, for all their modern hardware, may well constitute an anachronism. By underplaying the side of human thinking that involves conjecture and invention--a side that, as we have seen, has come increasingly into focus as performing a central role in man's mathematical, scientific, and aesthetic activities--automated instructional devices may lead educational practice back to a one-sided, overly rationalistic view of how thinking proceeds.

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19. See, for example, P. K. Komoski, op. cit.